HP³ RADIOMETER MEASUREMENTS FROM THE MARS MISSION INSIGHT.

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Introduction: The Heat Flow and Physical Properties Package (HP³) [1] includes an infrared Radiometer attached to the deck of the InSight lander [2]. The main objective of this part of the instrument is to constrain the surface thermal boundary condition of the heat flow measurement by the instrumented tether deployed into the subsurface. The heat flow in the subsurface can be affected by seasonal and diurnal temperature variations, by radiation from the lander, its shadow, and the change in surface albedo caused by dust removal during landing and later deposition. The radiometer will observe the seasonal variation over the course of the mission. Fitting of diurnal temperature curves provides an estimate of albedo and other thermophysical properties of the near surface.

HP³ RAD: The design is based on the MAscot RAdiometer (MARA) [3] and uses 6 thermopile sensors in a temperature stabilized sensor head. The thermopile sensors consist of a set of thermocouples with a hot junction in radiative heat exchange with the outside through a spectral bandpass filter. Temperature stabilization is achieved by controlled heating to a temperature setpoint above equilibrium temperature. An addition to the MARA design is a dust cover protecting the sensors during landing, that also is used as an calibration target via a controlled heater and a temperature sensor. After the opening of the dust cover, parts of it remain the sensor field of view so that regular calibration measurements can be performed, similar to the concept of the Mars Science Laboratory Rover Environmental Monitoring Station Ground Temperature Sensor [4]. The instrument observes two spots on the surface with 3 sensors each. The three sensors have different spectral bandpasses: 8-14, 8-10 and 16-19 micrometers.

RAD footprints: The two spots observed by the radiometer are in approximately 1.5 and 3 m distance N-N-W from the lander center (Fig. 1) The closer spot (FOV 1) could not be imaged by the arm camera. The stereo images of the farther spot (FOV2) show a flat surface with no rocks larger than cobbles. The closer spot (FOV1) likely also observes such a flat surface at a similar elevation below the lander deck. At the beginning and the end of the nominal mission, the shadows of the solar panels pass over the closer spot in the morning and afternoon. The temperature effect of the shadow is clearly seen in the afternoon at the time expected for a flat surface.

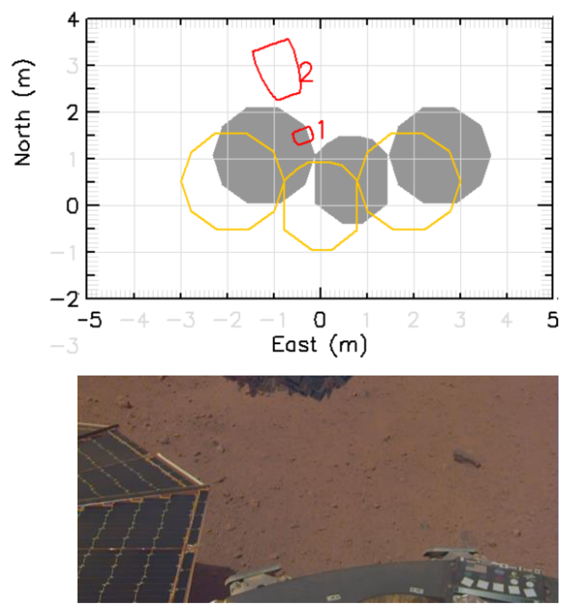

Figure 1: *Top: Plan view of the location of the radiometer footprints (red), the lander outline (yellow) and the lander shadow on sol 1, 15:10 hour LTST (gray). Coordinates relative to lander deck center. Bottom: Arm camera image of the FOV2 surface.*

RAD operations: The HP³ radiometer typically acquires data for five minutes at each full hour in local true solar time (LTST). Standard data sampling interval is 14 sec, but this can be decreased to 2 sec. Observations at different times or with longer durations can also be made.

Calibration measurements and uncertainty: After landing, the instrument acquired data with the cover closed and stabilized at the same temperature as the sensors. This provides the measurement offset introduced by the varying thermal environment. In addition to that, measurements with the calibration target temperature at various setpoints are made to determine the sensitivity of the thermopile sensors. These calibration measurements were repeated after the opening of the dust cover. These measurements receive only approximately 30 % of the signal from the calibration target and the rest from the Mars surface in the background, but will be repeated throughout the mission to detect any significant sensor degradation. The Mars background signal however has to be subtracted from the calibration signal. To achieve this the calibration measurements are bracketed by standard measurements so that the background can be interpolated between them. Additionally, the initial data analysis shows that the measured voltages do not change much from sol to sol, so that measurements from adjacent sols can be used for Mars surface background subtraction as well. The initial assessment of RAD data shows that the expected noise equivalent temperature difference of <1K at 170K is achieved. The uncertainty of the measurements based on the in-flight calibration is currently still being ascertained.

Anticipated results: We anticipate having finalized the calibration at the time of the conference. HP³ RAD will then have gathered data over approximately 100 sols, spanning an Ls of 295° to 358°. Data and power budgets frequently permitted the collection of hourly measurements for sols 14 to 39, (see Fig. 2). These diurnal curves represent the surface response to variation in insolation, and can be fit with diurnal curves derived from mathematical thermal models. The 24 measurements per sol might allow us to constrain more complex models [5], such as a duricrust that is observed near the surface and would likely manifest as vertical variation of thermal conductivity [6]. The depth to which the surface response can constrain subsurface properties depends on the period of the external forcing. The radiometer will – barring loss of instrument or spacecraft – observe the same two small spots for at least one full seasonal cycle. Unlike orbital [e.g. 7] or rover [5] measurements this provides complete seasonal coverage at high temporal sampling, and thus depth resolution, without any significant subpixel heterogeneity. The shadow of the solar panel passing through the spot observed by FOV1 presents an opportunity to probe somewhat shallower depth than the diurnal cycle. The temperature response to this passage has been observed in higher time resolution than the usual hourly measurements. Even shallower depths would be probed when the sun is eclipsed by the moon Phobos and Deimos for tens of seconds [8], but the first eclipse is only expected in the week of the conference. Another parameter constrained by the diurnal curves is surface albedo. From HIRISE images of the InSight landing site (ESP_058005_1845) it is obvious that the albedo in the vicinity of the lander has changed.

This is expected to have an impact on the measured subsurface heat flow, as it changes the temperature at the surface and thus introduces a transient heat flow while the soil adjusts to the new boundary condition. The albedo is expected to return to the original values as dust resettles over many months. The lander itself will also change surface temperatures in the vicinity via its shadow and thermal radiation [9], the effects of which can be observed by the radiometer.

The unprecedented temporal resolution and homogeneity of observed locations in addition to the atmospheric instrumentation of APSS [10] might allow us to constrain higher order effects such as sensible heat flux between atmosphere and surface [11].

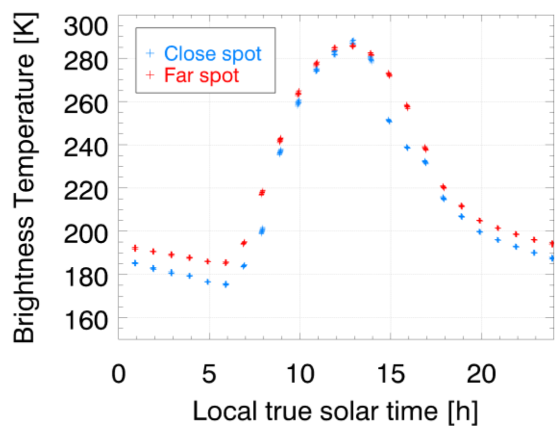

Figure 2:.*Broad bandpass data inverted with preliminary calibration coefficients based only on the closed cover calibration. Shown are data of sol 30 and 31*.

References: [1] Spohn, T. et al., *Space Sci. Rev.*, 214:96 (2018). [2] Banerdt, W.B., Russell, C.T., *Space Sci. Rev.*, 211, 1–3 (2017). [3] Grott, M. et al. Space Sci. Rev. 208:413 doi:10.1007/s11214-016-0272-1 (2017). [4] Gómez-Elvira, J. et al. Space Sci. Rev. 170: 583, doi:10.1007/s11214-012-9921-1(2012). [5] Vasavada et al. Icarus 284, 372–386, doi:10.1016 /j.icarus.2016.11.035 (2017). [6] Piqueux, S. & Christensen, P.R. JGR, VOL.116,E07004, doi:10.1029 /2011JE003805, (2011). [7] Putzig, N.E. & Mellon, M. T. Icarus 19, 168–94, doi:10.1016/j.icarus.2007.05.013 (2007). [8] Piqueux, S. & Christensen, P.R. GRL, vol.39, L21203, doi:10.1029/2012GL053352, (2012). [9] Siegler, M. et al. Space Sci Rev. 211: 259, doi:10.1007/s11214-017-0331-2 (2016) [10] Banfield, D. et al., *Space Sci. Rev.*, 215:4, doi:10.1007/s11214-018-0570-x (2018). [11] Spiga, A. et al. Space Sci Rev 214:109, doi:10.1007/s11214-018-0543-0(2018)